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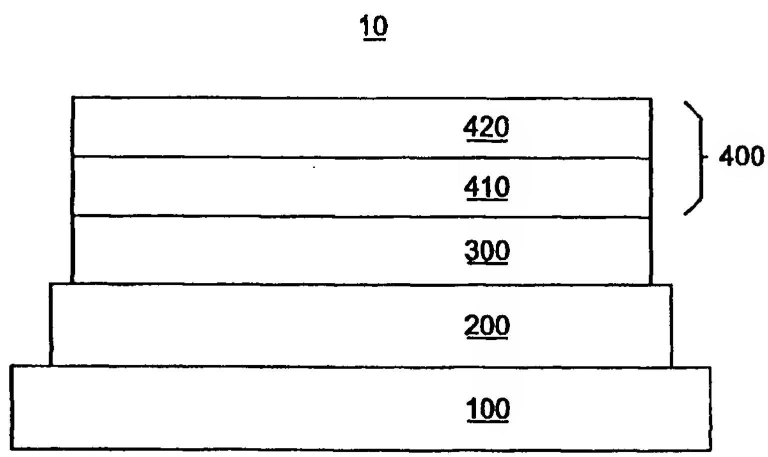

(57) Abstract

The present invention is directed to an organic light emitting diode device (10) having a substrate (100), a first conductor (200) formed on the substrate (100), an organic stack (300) formed on the first conductor (200), and a second conductor (400) formed on the organic stack (300). In accordance with the present invention, at least one of the first conductor (200) and the second conductor (400) includes a thin layer of dielectric material (410), and a conducting layer (420). The conducting layer (420) may be transparent. The thin layer of dielectric material may include a doped dielectric material. The doped dielectric material may include between 5 % and 50 % of a conducting material. The conducting material may include one of Mg, Ca, Ce, Ba, Al, Sn, Ga, and In. In accordance with the present invention, the thin layer of dielectric material (410) may include one of lithium fluoride, cesium fluoride, and silicon monoxide.

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HIGH EFFICIENCY ELECTRODES FOR ORGANIC LIGHT EMITTING DIODE DEVICES

CROSS REFERENCE TO RELATED APPLICATIONS

The present invention relates to and claims priority on U.S. Provisional Patent Application Serial No. 60/125,239, filed on March 19, 1999.

FIELD OF THE INVENTION

The present invention relates to organic light emitting diode ("OLED") devices. In particular, the present invention relates to the use of doped conductors in organic light emitting devices.

BACKGROUND OF THE INVENTION

OLED devices have been known for approximately two decades. All OLEDs work on the same general principles. An OLED is typically a thin filmed structure formed on a substrate. A light-emitting layer of a luminescent organic solid, as well as adjacent semiconductor layers, are sandwiched between a cathode and an anode. The semiconductor layers may be hole-injecting or electron-injecting layers. The light-emitting layer may be selected from any of a multitude of fluorescent organic solids. The light-emitting layer may consist of multiple sublayers.

When a potential difference is applied across the device, negatively charged electrons move from the cathode to the electron-injecting layer and finally into the layer(s) of organic material. At the same time positive charges, typically referred to as holes, move from the anode to the hole-injecting layer and finally into the same organic light-emitting layer. When the positive and negative charges meet in the center layers (i.e., the semiconducting organic material), they combine, and produce photons. The wave-length -- and consequently the color -- of the photons depends on the electronic properties of the organic material in which the photons are generated.

The color of light emitted from the OLED device can be controlled by the selection of the organic material. White light is produced by generating and mixing blue, red and green lights simultaneously. The precise color of the light emitted by a particular structure can be controlled both by the selection of the organic material, as well as by the selection of dopants.

In a typical OLED, either the cathode or the anode is transparent. The cathode is typically constructed of a low work function material. The holes are typically injected from a high work function anode material into the organic material via a hole transport layer. Typically, the devices operate with a DC bias of 2 to 30 volts. The films may be formed by evaporation, spin casting or other appropriate polymer film-forming techniques, or chemical self-assembly. Thicknesses typically range from a few mono layers to about 1 to 2,000 angstroms.

OLEDs typically work best when operated in a current mode. The light output is much more stable for constant current drive than for a constant voltage drive. This is in contrast to many other display technologies, which are typically operated in a voltage mode.

An active matrix display using OLED technology, therefore, requires a specific pixel architecture to provide for a current mode of operation. In a typical matrix-addressed OLED device, numerous OLEDs are formed on a single substrate and arranged in groups in a regular grid pattern. Several OLED groups forming a column of the grid may share a common cathode, or cathode line. Several OLED groups forming a row of the grid may share a common anode, or anode line. The individual OLEDs in a given group emit light when their cathode line and anode line are activated at the same time.

OLEDs have a number of beneficial characteristics. These include a low activation voltage (about 5 volts), fast response when formed with a thin light-emitting layer, and high brightness in proportion to the injected electric current. OLEDs also provide high visibility due to self-emission, as well as superior impact resistance, and ease of handling of the solid state devices in which they are used. OLEDs have practical application in television, graphic display systems, and digital printing.

Optimization of charge injection and transport are of critical importance in providing bright and efficient OLEDs. The use of low work function metals, such as lithium, calcium, and magnesium, as cathodes generally results in efficient but unreliable OLEDs. The unreliability is primarily due to the reactive nature of these materials, especially when exposed to uncontrolled atmospheric conditions. More stable materials. such as aluminum, silver, etc., are generally preferred as cathodes. However, OLEDs that include cathodes made from these materials are inefficient, and their light output is very low compared to OLEDs with a reactive metal cathode.

Alternatives that employ an Al:Li alloy (0.1% Li) have been used to fabricate efficient and stable OLEDs. These devices, however, are difficult to reproduce because the Li content in Al is difficult to control during the co-evaporation process. Other alternatives employ a thin insulating film such as lithium fluoride (LiF), deposited between the organic layer and the Al cathode. These OLED devices are easier to reproduce, but do not produce the desired efficiency. In addition to LiF, other materials such as silicon dioxide, magnesium fluoride, calcium fluoride, sodium chloride, hexatriacontane. cesium carbonate, etc., have been used as insulating layers in OLEDs fabrication. These materials, however, provide no better enhancement in device performance and stability than devices that include a LiF buffer layer.

More recent developments in OLEDS include employing a co-deposited composite cathode of Al:LiF as disclosed in Jabbour et. al, "Aluminum based cathode structure for enhanced electron injection in electroluminescent organic devices," 73 Applied Physics Letters 1185 (1998). The OLEDs employ only a small percentage of dielectric material (alkali fluorides e.g. LiF) in the cathode, typically 1 to 3 percent. These OLEDs are down emitting and employ non transparent cathodes.

Although substantial progress has been made in the development of OLEDs to date, substantial additional challenges remain. There is a need for a method of improving the conduction and efficiency of the conductors within OLEDs. A high transparency cathode or anode with good carrier injection efficiency is needed for OLED devices that emit light upward, away from the substrate.

The present invention provides a solution to the current problems by increasing the luminous efficiency for OLED devices that include substrates formed from silicon integrated circuits or metal foil.

OBJECTS OF THE INVENTION

It is therefore an object of the present invention to provide an organic light emitting device with improved luminous efficiency.

It is another object of the present invention to provide a high efficiency electrode for an OLED device.

It is another object of the present invention to provide a high efficiency electrode for an upwardly emitting OLED device.

It is another object of the present invention to provide a display comprising a plurality of organic light emitting devices with improved luminous efficiency.

It is another object of the present invention to improve light transmissions in up-emitting organic light emitting devices.

It is another object of the present invention to provide a conductor with improved carrier injection efficiency in organic light emitting devices.

It is another object of the present invention to provide a transparent cathode with improved carrier injection efficiency in up-emitting organic light emitting devices.

It is another object of the present invention to provide a transparent anode with improved carrier injection efficiency in up-emitting organic light devices.

It is another object of the present invention to increase the effective light emitting active are on active matrix substrates.

It is another object of the present invention to provide an electrode formed from semitransparent conductor doped dielectric films and a transparent top conductor.

Additional objects and advantages of the invention are set forth, in part, in the description which follows, and, in part, will be apparent to one of ordinary skill in the art from the description and/or from the practice of the invention.

SUMMARY OF THE INVENTION

In response to the foregoing challenges, applicants have developed an innovative OLED electrode and process for fabricating an OLED. The present invention is directed to an organic light emitting diode device having a substrate, a first conductor formed on the substrate, an organic stack formed on the first conductor, and a second conductor formed on the organic stack. In accordance with the present invention, at least one of the first conductor and the second conductor includes a thin layer of dielectric material, and a conducting layer. In accordance with one embodiment of the present invention, the first conductor may include the thin layer of dielectric material, and the conducting layer. In accordance with another embodiment of the present invention, the second conductor may include the thin layer of dielectric material, and the conducting layer. In accordance with another embodiment of the present invention, each of the first conductor and the second conductor includes the thin layer of dielectric material, and the conducting layer. The second conducting layer may be either a cathode or an anode.

The conducting layer may be transparent. The thin layer of dielectric material may include a doped dielectric material. The doped dielectric material may include between 5% and 50% of a conducting material. The conducting material may include one of Mg, Ca, Ce, Ba, Al, Sn, Ga and In. In accordance with the present invention, the thin layer of dielectric material may include one of lithium fluoride, cesium fluoride and silicon monoxide.

The present invention is also directed to a conductor layer for an organic light emitting diode display. The conductor layer includes a thin layer of dielectric material, and a conducting layer.

The conducting layer may be transparent. The thin layer of dielectric material may include a doped dielectric material. The doped dielectric material may include between 5% and 50% of a conducting material. The conducting material may include one of Mg, Ca, Ce, Ba, Al, Sn, Ga and In. In accordance with the present invention, the thin layer of dielectric material may include one of lithium fluoride, cesium fluoride and silicon monoxide.

The present invention is also directed to a method of fabricating an organic light emitting diode device. The method includes the steps of providing a substrate, forming a first conductor layer on the substrate, forming an organic stack on the first conductor layer, and forming a second conductor layer on the organic stack. In accordance with the present invention, one of the step of forming the first conductor layer and the step of forming the second conductor layer includes the steps of forming a doped dielectric material layer and forming a layer of conducting material such that the doped dielectric material layer is located adjacent the organic stack. The step of forming a doped dielectric material layer may include the step of co-evaporating a transparent dielectric material with a conducting material.

It is to be understood that both the foregoing general description and the following detailed description are exemplary and explanatory only, and are not restrictive of the invention as claimed. The accompanying drawings, which are incorporated herein by reference and which constitute a part of this specification, illustrate certain embodiments of the invention, and together with the detailed description serve to explain the principles of the present invention.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will be described in conjunction with the following drawings in which like reference numerals designate like elements and wherein:

Fig. 1 is a cross-sectional side view of a conventional OLED device;

Fig. 2 is a cross-sectional side view of an OLED device according to the present invention;

Fig. 3 is a cross-sectional side view of an OLED device according to another embodiment of the present invention; and

Fig. 4 is a cross-sectional side view of an OLED device according to another embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

Fig. 1 discloses the basic structure of an organic light emitting device ("OLED"). The OLED **15**, shown in Fig. 1, includes a substrate **100**. Overlying the substrate **100** is a first conductor **200**. Overlying the first conductor **200** is a second conductor **400**. Sandwiched between the conductor layers is a layer or a stack of layers of light emitting organic material **300**.

The substrate **100** is substantially planar and underlies and provides support for the entire OLED structure. The first and second conductors **200** and **400** function as either electron injecting or hole injecting layers. When the positive and negative charges from the conductors meet in the

layer of organic material **300**, light is emitted. OLED **15** may emit light through either the second conductor **400** or the substrate **100**.

An OLED device **10** according to the present invention is shown in Fig. 2. The substrate **100** may be formed from silicon or a metal foil. Furthermore, the substrate 100 may include integrated circuitry for operating the OLED device **10**. The OLED device **10** further includes a first conductor **200** and an organic stack **300**. The second conductor **400** of the up-emitting OLED device **10** includes a conducting layer **420** and a layer of dielectric material **410**. The layer of dielectric material **410** is located between the conducting layer **420** and the organic stack **300**. The organic material **300** may include multiple layers of materials (e.g. AlQ/AlQ + dopant/NPB/CuPc). It is contemplated that polymers, small molecule organics or combinations thereof may be employed in the layers of organic material **300**.

The dielectric layer **410** is preferably formed of a thin film (<50nm) of transparent dielectric. The transparent dielectric may be formed of lithium fluoride, cesium fluoride, or silicon monoxide. It is contemplated that other suitable materials having similar electrical and physical properties may be used to form the transparent dielectric. The dielectric **410** is preferably doped to include between 5 and 50 percent of conducting material. The conducting material may include, for example, Mg, Ca, Ce, Ba, Al, Sn, Ga, or In. The conducting material serves to insure vertical conduction and to enhance carrier injection. The conductor doping of the dielectric layer **410** also minimizes the need for precise thickness control of the dielectric layer **410** and provides a barrier for damage during subsequent sputter depositions of the transparent top conductor cathode **420** (e.g., sputtered ITO, IAO, or IZO). Thin metal layers (e.g., <20nm) can be used as the transparent electrode **420** instead of ITO or IZO. Thin metal layers, however, are not preferred for most applications since they are more opaque than the intrinsically transparent conductors. It is contemplated that the second conductor **400** may serve as either the anode or cathode in accordance with embodiments of the present invention. It is contemplated that other suitable dielectric host and conductor dopant materials having suitable electrical and physical properties are considered to be well within the scope of the present invention.

The selection of both the dielectric material and the doping material determines the improvement of carrier injection into the OLED device. For example, selecting CsF doped with Ca or Mg works well when second conductor **400** serves a cathode. and selecting either LiF or SiO doped with Al or Sn works well when second conductor **400** functions as an anode. The preferred material selections for anode contacts also work reasonably well as cathode contacts and the reverse

is generally true with the preferred materials for cathode contacts. Below the organic material **300**, is the bottom conductor **200**. The conductor **200** is preferably formed from 20nm Mo over 40nm Cr.

The present invention may also can be used to increase the effective light emitting active area on active matrix substrates. The present invention improves the up-emitting characteristics of the OLED device **10**, thereby permitting the OLED device to be constructed over the substrate transistors. In prior designs, OLED devices were required to emit between the transistors. The improvement increases increasing peak luminance or life.

The process of forming an OLED device **10** utilizing a conductor in accordance with the present invention will now be described. The basic OLED device stacked structure is constructed by first forming the first conductor **200** on the substrate **100** using conventional techniques. The organic stack **300** is then deposited in layers on the first conductor **200**. This includes depositing a final layer of organic light emitting material (e.g., preferably an electron transport layer including Alq_3).

The process of forming the second conductor **400** as a cathode will now be described. A layer of doped dielectric material **410** is then co-evaporated on the final layer of the organic stack **300**. Preferably a thin layer of 5nm is formed from the co-evaporation in a vacuum of CsF with 30wt% Mg through a shadow mask opening onto the planned cathode area of the device. The co-evaporation of the dielectric layer **410** may begin with a higher dopant concentration such as up to 98% conductor for the first 0.5-3nm before increasing the conductor deposition rate to reach a less than 50 percent conductor concentration overall. The conductor-dielectric concentration change may be abrupt or gradual. The transparent conductor **420** is then deposited over doped dielectric layer **410**. The conductor **420** is preferably formed from indium-tin oxide (ITO) that is sputter deposited in a very low pressure argon and ~1% oxygen atmosphere.

The process of forming the second conductor **400** as an anode will now be described. When constructing the second conductor **400** as the anode. the doped dielectric material **410** is preferably formed by co-evaporating a thin layer (approximately 5nm) of LiF or SiO with 30 wt% In or Sn through a shadow mask opening onto to the planned anode area of the device. The transparent conductor **420** is then deposited over doped dielectric layer **410**.

It is further contemplated that in accordance with the present invention. the dielectric material may be placed under the organic stack **300**, as shown in Fig. 3. Fig. 3 discloses an OLED device **20** in accordance with another embodiment of the present invention. In the OLED device **20**, the

first conductor **200** includes a conductor layer **210** and a layer of doped dielectric material **220**. This composite layer can be under or on top of the stack of light emitting organic material **300** depending on the desired current direction through the device. When the dielectric material **220** is placed under the organic material **300** and on top of a conducting electrode **210**, then the bottom conductor or electrode **210** does not have to be formed from a transparent material (i.e., ITO) because an up-emitting OLED does not require a transparent first conductor **200**. The process used to form layers **410** and **420**, described above, is performed to form layers **210** and **220**.

A semi-transparent OLED device can be formed if transparent conductors (e.g., ITO) are used on both sides of the organic material **300**. It is further contemplated that in accordance with the present invention, the dielectric material may be placed on both sides of the organic stack **300**, as shown in Fig. 4. Fig. 4 discloses an OLED device **30** in accordance with another embodiment of the present invention. In the OLED device **30**, doped dielectric layers **220**, **410** are formed on both sides of the light emitting organic material **300**.

It will be apparent to those skilled in the art that various modifications and variations may be made in the preparation and configuration of the present invention without departing from the scope and spirit of the present invention. For example, an OLED may include a top cover overlying the conductors and the organic material. Thus, it is intended that the present invention covers the modifications and variations of the invention, provided they come within the scope of the appended claims and their equivalents.

WHAT IS CLAIMED IS:

1. In an organic light emitting diode device having a substrate, a first conductor formed on said substrate, an organic stack formed on said first conductor, and a second conductor formed on said organic stack, the improvement comprising:

at least one of said first conductor and said second conductor comprising:

a thin layer of dielectric material; and

a conducting layer.

2. The organic light emitting diode device according to Claim 1, wherein said first conductor includes said thin layer of dielectric material, and said conducting layer.

3. The organic light emitting diode device according to Claim 1, wherein said second conductor includes said thin layer of dielectric material, and said conducting layer.

4. The organic light emitting diode device according to Claim 1, wherein each of said first conductor and said second conductor includes said thin layer of dielectric material, and said conducting layer.

5. The organic light emitting diode device according to Claim 1, wherein said conducting layer is transparent.

6. The organic light emitting diode device according to Claim 1, wherein said thin layer of dielectric material includes a doped dielectric material.

7. The organic light emitting diode device according to Claim 6, wherein said doped dielectric material includes between 5% and 50% of a conducting material.

8. The organic light emitting diode device according to Claim 7, wherein said conducting material includes one of Mg, Ca, Ce, Ba, Al, Sn, Ga and In.

9. The organic light emitting diode device according to Claim 1, wherein said thin layer of dielectric material includes one of lithium fluoride, cesium fluoride and silicon monoxide.

10. The organic light emitting diode device according to Claim 9, wherein said thin layer of dielectric material includes a doped dielectric material.

11. The organic light emitting diode device according to Claim 10, wherein said doped dielectric material includes between 5% and 50% of a conducting material.

12. The organic light emitting diode device according to Claim 11, wherein said conducting material includes one of Mg, Ca, Ce, Ba, Al, Sn, Ga and In.

13. The organic light emitting diode device according to Claim 1, wherein said second conductor is a cathode.

14. The organic light emitting diode device according to Claim 1, wherein said second conductor is an anode.

15. The organic light emitting diode device according to Claim 1, wherein said thin layer has a thickness of less than 50nm.

16. A conductor layer for an organic light emitting diode display, said conductor layer comprising:

a thin layer of dielectric material; and

a conducting layer.

17. The conductor layer according to Claim 16, wherein said conducting layer is transparent.

18. The conductor layer according to Claim 16, wherein said thin layer of dielectric material includes a doped dielectric material.

19. The conductor layer according to Claim 18, wherein said doped dielectric material includes between 5% and 50% of a conducting material.

20. The conductor layer according to Claim 19, wherein said conducting material includes one of Mg, Ca, Ce, Ba, Al, Sn, Ga and In.

21. The organic light emitting diode device according to Claim 16, wherein said thin layer of dielectric material includes one of lithium fluoride, cesium fluoride and silicon monoxide.

22. The organic light emitting diode device according to Claim 21, wherein said thin layer of dielectric material includes a doped dielectric material.

23. The organic light emitting diode device according to Claim 22, wherein said doped dielectric material includes between 5% and 50% of a conducting material.

24. The organic light emitting diode device according to Claim 23, wherein said conducting material includes one of Mg, Ca, Ce, Ba, Al, Sn, Ga and In.

25. The organic light emitting diode device according to Claim 16, wherein said thin layer has a thickness of less than 50nm.

26. A method of fabricating an organic light emitting diode device, said method comprising the steps of:

providing a substrate;

forming a first conductor layer on said substrate:

forming an organic stack on said first conductor layer; and

forming a second conductor layer on said organic stack, wherein one of said step of forming said first conductor layer and said step of forming said second conductor layer includes the steps of

forming a doped dielectric material layer and forming a layer of conducting material such that said doped dielectric material layer is located adjacent said organic stack.

27. The method according to Claim 26, wherein said step of forming a doped dielectric material layer includes the step of co-evaporating a transparent dielectric material with a conducting material.

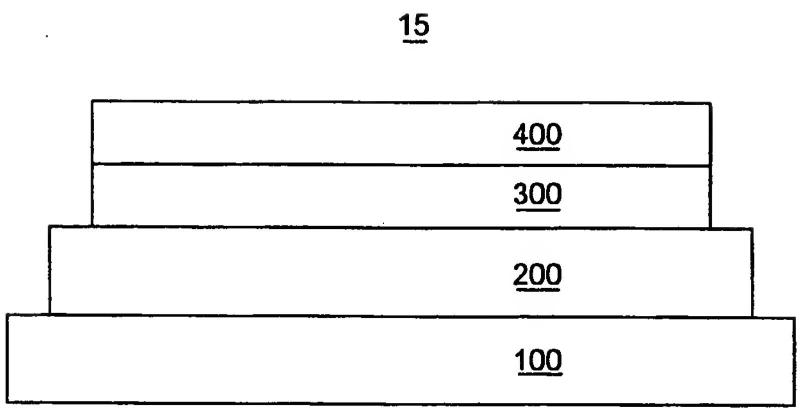

FIG. 1
PRIOR ART

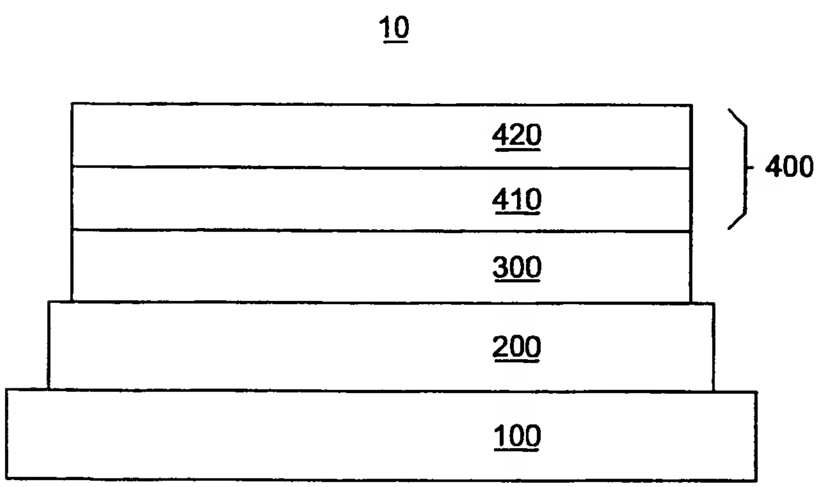

FIG. 2

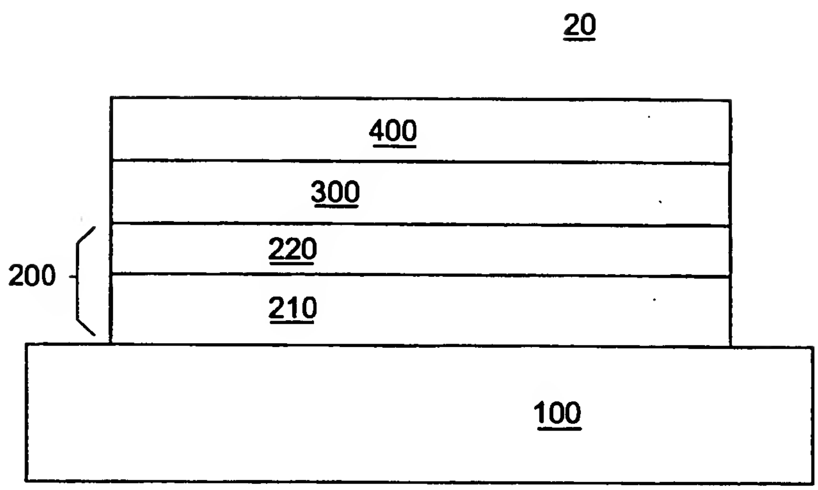

FIG. 3

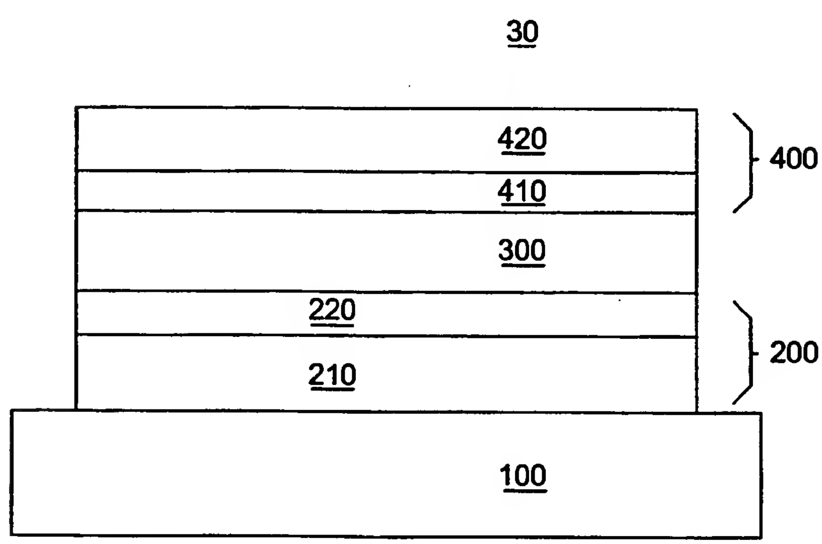

FIG. 4

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US00/06929

A. CLASSIFICATION OF SUBJECT MATTER
IPC(7) :H01J 1/62
US CL :313/503, 506, 507, 508, 509, 511, 512
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
U.S. : 313/503, 506, 507, 508, 509, 511, 512

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
None

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
None

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	US 5,674,217 A (KANG) 7 October 1997 (07.10.97), column 3, line 45- column 4, line 17	1-5, 9, 13-16, 21, 26, 27 11, 12, 22-24
X Y	US 5,314,759 A (HARKONEN et al.) 24 May 1994 (24.05.94), column 3, line 23 - column 5, line 64	1, 6-8, 10, 16-20, 25 11-12, 22-24

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:
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Date of the actual completion of the international search	Date of mailing of the international search report
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